UNITED STATES NON-PROVISIONAL PATENT APPLICATION

FLAT LINEAR VOICE COIL ACTUATOR WITH PLANAR COILS AND A SPRING-TYPE CHARACTERISTIC

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Related Applications

The present application claims priority under 35 U.S.C. §119(e) from provisional application number 60/420,483, filed 10/21/2002.

Technical Field

The present invention relates generally to linear voice coil actuators, and in particular to linear voice coil actuators using a planar coil configuration and providing a force versus stroke characteristic matched to a load characteristic, such as a spring-type characteristic.

Background Art

A new linear voice coil actuator with planar coils is disclosed in U.S. Provisional Patent Application No. 60/343,488 (" '488 Provisional Application"), which has been incorporated in U.S. Non-Provisional Application 10/327,316, filed December 20, 2002, assigned to the assignee of the subject application, and incorporated herein by reference. In the '488 Provisional Application, the magnets adjacent to each other in each field sub-assembly are attached to the field blanks in such a way that they form poles of alternating polarities: North–South–North or South–North–South. According to the above '488 Provisional Application, there is provided an additional magnetic flux path 24 for each pair of the magnets 22A/22B of opposite polarity that are separated by the air gap 26, as can be seen in Fig. 5 of this and the referenced application.

Traditionally, desired force versus stroke characteristics are obtained in linear actuators by controlling the current being supplied to the actuator coil or coils. Thus, open or closed loop control functions may be required to control the current being applied to the coils as a function of the stroke position so as to produce a desired magnitude of force at various positions of the stroke.

Providing such control functions can involve significant costs and complexities beyond the design of the actuator itself.

It is therefore desirable to have a linear actuator that is capable of providing selected force versus stroke characteristics at a lower cost and complexity than in the past. It is also desirable to have such a linear actuator in which the need for open or closed loop control of the actuator coil current can be reduced or eliminated.

Summary of the Invention

The above problems and disadvantages of prior linear actuators are addressed by the present invention of an actuator for operating upon a load having load characteristics, including a field assembly comprising a plurality of magnets configured to provide flux density distributions selected as a function of the load characteristics. The configuration of the plurality of magnets can be generalized to a magnetic structure which is dimensioned to provide the desired flux density distributions.

The plurality of magnets can be arranged in a sequence so that at least two adjacent ones of the plurality of magnets having a first polarity are followed by at least another of the plurality of magnets having a polarity different from the first polarity, and flux distributions provided by the sequence correspond to the load characteristics.

In one embodiment of the linear actuator of the present invention, a first plurality of magnets of one polarity is followed by a second plurality of magnets of a different polarity positioned on the first field blank in a direction of motion of the linear actuator. A coil assembly is provided including a generally planar coil comprising a first force generating portion spaced apart from a second force generating portion so that the first force generating portion is positioned over ones of the first plurality of magnets whenever the second force generating portion is positioned over ones of the second plurality of magnets.

In particular, an embodiment of the present invention includes a plurality of field sub-assemblies each comprising a field blank, wherein a first one of the plurality of field sub-assemblies includes consecutive groups of magnets. Each

one of the consecutive groups of magnets includes a plurality of magnets arranged to have a selected magnetic polarity and to have a selected magnetic flux density distribution. The first one of the plurality of field sub-assemblies is positioned with respect to a second one of the plurality of field sub-assemblies to form a gap between them. A coil assembly is provided which includes at least one coil positioned in a plane within the gap, wherein the plane is substantially parallel to the direction of motion of the linear coil actuator.

In this embodiment of the linear actuator, the field blanks of each of the plurality of field sub-assemblies comprise a generally planar portion, and additional sections extending along edges of the planar portion in the direction of motion. When first and second ones of the plurality of field sub-assemblies are positioned to form the gap, corresponding additional sections of the field blanks in the first and second field sub-assemblies are adjacent one another and form a flux path perpendicular to the direction of motion for a magnet of the first field sub-assembly.

By configuring the distribution of the flux densities in the air gap to correspond to expected load characteristics, for example, by using a plurality of magnets creating different average flux densities, to which the coil is exposed, there can be a reduction or elimination of any requirement of a control function for controlling the magnitude and timing of current supplied to the actuator coil or coils.

The present invention also includes a method for configuring a linear actuator having a field assembly and a coil assembly for operation upon a load having load characteristics which vary over a stroke, which comprises the steps of fashioning a magnet structure of the field assembly along a direction of motion of the linear actuator to distribute flux densities in correspondence to the variations in the load characteristics over the stroke; and configuring a coil of the coil assembly to be responsive to the distributed flux densities.

These concepts can be employed in a flat linear voice coil actuator with planar coils, to produce a compact, low cost actuator with a selected force versus stroke characteristic, such as that of a spring having a spring constant K.

It is therefore an object of the present invention to provide an actuator in which a magnet structure of the field assembly provides distributed flux densities over the stroke of the actuator in correspondence to required load characteristics.

It is a further object of the present invention to provide a linear actuator employing generally planar coils and a plurality of sized magnets arranged in a sequence and a pattern of polarities to provide a distribution of flux densities over the stroke which correspond to a required load characteristic.

It is another object of the present invention to provide a linear actuator which provides a force versus stroke characteristic that corresponds to a required load characteristic, such as a spring characteristic, with a reduced requirement for any coil current control mechanisms.

It still another object of the present invention to provide a method for configuring a linear actuator so that the magnet structure of the field assembly of the actuator provides a distribution of flux densities in the air gap over the stroke which corresponds to a required load characteristic.

These and other objectives, features and advantages of the present invention will be better understood upon consideration of the following detailed description and accompanying drawings.

Description of the Drawings

Fig. 1 is a simplified perspective view of an embodiment of a linear voice coil actuator in accordance with the present invention.

Fig. 2A is a simplified perspective view of two field sub-assemblies of an embodiment of the present invention.

Figs. 2B and 2C are simplified illustrations of possible orientations of a coil of the coil sub-assembly, and magnets of the field sub-assembly, of an embodiment of the present invention.

Fig. 3 is a simplified illustration of the coil sub-assembly of an embodiment of the present invention.

Fig. 4 is an exploded view of the linear voice coil actuator embodiment of Fig. 1.

Fig. 5 is a simplified cross sectional view of the linear actuator of Fig. 1, taken along lines 5-5 shown in Fig. 2A.

Fig. 6 is an illustrative plot of a Force versus Stroke characteristic for the embodiment of the invention depicted in Fig. 2A.

Detailed Description of the Invention

The embodiment of the present invention shown as linear voice coil actuator 10 in Fig. 1 includes two field sub-assemblies 12, 14, and a coil assembly 16. Fig. 2A provides a view of sub-assemblies 12 and 14, while Fig. 3 provides a more complete view of coil assembly 16. The embodiment shown in Fig. 1 is analogous to an actuator described in the above '488 Provisional Application but differs in at least the following aspect:

> In the above '488 Provisional Application, the magnets adjacent to each other in each field sub-assembly are attached to the field blanks in such a way, that they form the poles of alternating polarities: North – South – North or South – North – South. In contrast, in accordance with the embodiment of Figs. 1 and 2A, in each field sub-assembly there are at least two magnets of the same polarity spaced apart from each other and from another group of magnets of the opposite polarity, which form the poles of alternating polarity. An example of this pattern is provided in Fig. 2A.

The pattern shown in Fig. 2A may be repeated along the direction of motion 19. This repetition of the pattern can be done to increase the force of the actuator. For example, if two sets of four magnets were used instead of one, the force developed by the actuator would be twice as high. In this case, two coils would be required.

Fig. 4 shows a one-coil arrangement of the present invention. Fig. 5 depicts a cross-section of the actuator along line 5-5 of Fig. 2A. (The coil of the actuator is not shown for simplicity.) It is to be noted that the arrangement provides another path 24 for magnetic flux from each pair of the magnets of opposite polarity that are separated by the air gap 26, for example, magnets 22A and 22B. The cross-section of the actuator illustrated in Fig. 5 is taken

perpendicular to the direction of motion 19 (see Fig. 2A), which is into or out of the page in Fig. 5. The field blanks in this embodiment may include additional sections 30 which provide flux paths perpendicular to the direction of motion for each pair of magnets of opposite polarity that are separated by the gap. In other words, provided in this embodiment of the present invention are flux paths which lie generally in a plane perpendicular to the direction of motion 19.

This above described configuration of a linear actuator in accordance with the present invention can result in a design with a characteristic similar to that of a mechanical spring (see Fig. 6), or other desired load characteristic.

The methodology of the present invention, implemented in the embodiments disclosed in the figures, is to distribute the magnetic field sources across the stroke area of the field sub-assemblies to provide a magnetic field distribution in the air gap which better matches the characteristics of the load being handled by the actuator. By tailoring the distribution of the magnetic field sources in this manner, one can simplify the actuator design, and substantially reduce or eliminate the need to control the current applied to the coil in order to obtain desired force characteristics. This distribution of magnetic field sources can take the form of varying the size of each of the magnets, such as varying the widths of the magnets as a function of stroke position along the field assembly, so that the magnetic flux density in the air gap varies as a function of stroke position.

For example, in the embodiment of the present invention depicted in Fig. 2A, the sizing and distribution of the magnets 22A/22B, 32A/32B, 34A/34B and 36A/36B, are selected to match a particular load, namely a spring having a spring constant K, and the frictional forces expected to be present in the actuator. The group of magnets 22B and 32B provide a distributed magnetic field having a South polarity, while the group of magnets 22A and 32A provide a distributed magnetic field having a North polarity. Magnets 22A and 22B are smaller in size, (in this embodiment, smaller in width) than magnets 32A and 32B of their respective groups.

Therefore, in the depicted embodiment in Fig. 2A, at the beginning of the stroke of the actuator, the force generating sections of coil 18 are positioned between the magnet pairs 22A/22B and 34A/34B having the smaller size, and therefore lower average flux density to which the coil is exposed. At the end of the stroke, the force generating portions of coil 18 are positioned between magnet pairs 36A/36B and 32A/32B which are larger in size and therefore provide a higher average flux density. As a result, coil 18 generates a greater force at the end of the stroke as compared with the beginning of the stroke. Fig. 2B illustrates the position of coil 18 (in phantom) at the beginning of the stroke, and Fig. 2C illustrates the position of coil 18 (in phantom) at the end of the stroke.

In Figs. 2B and 2C, it can be seen that coil 18 has a first force generating portion spaced apart from a second force generating portion. In Fig. 2B, it can be seen that the spacing of the first and second force generating portions is set so that the first force generating portion is positioned over the smaller magnet of North polarity while the second force generating portion is positioned over the smaller magnet of South polarity. This spacing is such that in Fig. 2C, at the end of the stroke, the first force generating portion is positioned over the larger magnet of North polarity while the second force generating portion is positioned over the larger magnet of South polarity. Thus, in this arrangement, the first force generating portion is positioned over ones of the magnets of North polarity whenever the second force generating portion is positioned over ones of the magnets of South polarity .

It will be appreciated by those skilled in the art that the result is a stroke versus force pattern that can closely match the load characteristics of a spring.

Preferably, the magnetic field distribution in the air gap provided by the permanent magnets matches the expected load and friction characteristics as closely as possible. In this way, the need to control the current being supplied to the coil in order to provide the desired stroke versus force characteristics can be minimized or eliminated. If variations in the load are expected, the magnitude of

the magnetic field is preferably increased above what would be needed to provide the nominal load characteristics.

In the embodiment of the present invention depicted, for example, in Fig. 2A, and which can provide the force versus stroke characteristics of Fig. 6, the widths of the smaller magnets 22A/22B and 34A/34B are about 40 per cent of the width of the larger magnets 32A/32B and 36A/36B of their respective polarity group.

In another embodiment of the invention, only one of the field sub-assemblies, 12 or 14, needs to have any magnets. In this embodiment, the permanent magnets would be positioned on only one side of the coil or coils 18.

Therefore, one embodiment of the invention involves a linear coil actuator including a plurality of field sub-assemblies, and a coil assembly. The plurality of field sub-assemblies each comprise a field blank, and at least one of the plurality of field sub-assemblies also includes a plurality of magnets of the same and alternating polarity and of the same or different widths in the direction of motion. The plurality of field sub-assemblies are positioned with respect to one another to form a gap between the at least one of the plurality of field assemblies which includes the plurality of magnets, and another of the plurality of field assemblies. The coil assembly of this embodiment includes coils that are positioned in the same plane within the gap, wherein the plane is substantially parallel to the direction of motion of the linear coil actuator.

Another embodiment of the present invention is directed to a linear coil actuator including a plurality of field sub-assemblies with additional sections, and a coil assembly. The plurality of field sub-assemblies each comprise a field blank, and at least one of the plurality of field sub-assemblies also includes a plurality of magnets of the same and alternating polarity and of the same or different widths in the direction of motion, wherein the magnets are spaced apart from each other. The plurality of field sub-assemblies are positioned with respect to one another to form a gap between the at least one of the plurality of field assemblies which includes the plurality of magnets, and another of the plurality of field assemblies. The field blanks in this embodiment further include additional

sections which provide a flux path perpendicular to the direction of motion for each pair of magnets of opposite polarity that are separated by the gap.

In a further embodiment of the above linear coil actuator, the field blanks of each of the plurality of field sub-assemblies comprise a generally planar portion, and the additional sections extend above the planar portion and along the direction of motion. When a first one of the plurality of field sub-assemblies and a second one of the plurality of field sub-assemblies are positioned to form the gap, the additional sections of the first and second field sub-assemblies are positioned in contact with or adjacent one another. The provided perpendicular flux path is formed through a magnet of the first field subassembly, across the gap to a magnet of opposite polarity (if any) of the second field subassembly, through the planar portion and then one of the additional sections of the field blank of the second field subassembly, through the adjacent additional section and then the planar portion of the first field subassembly, and back to the magnet of the first field subassembly. (In embodiments in which only one of the field assemblies includes magnets, the perpendicular flux path will extend from a magnet of the one field assembly, across the gap, and to the planar portion of the opposite field assembly.)

In the above described embodiments, the magnetic flux density distribution which is provided by the magnets in the air gap is varied by manipulating the distribution of the magnetic field sources -- for example, by manipulating the number and size of magnets used to provide each polarity grouping. Thus, a South polarity magnet grouping can have two magnets of the same or different size so that the magnitude of the South polarity magnetic flux density that is provided as a function of coil position will depend upon the order and location in which these magnets are arranged.

In accordance with the present invention, a linear voice coil actuator includes a plurality of field sub-assemblies, and a coil assembly. The plurality of field sub-assemblies each comprise a field blank, and at least one of the plurality of field sub-assemblies also includes a plurality of groups of magnets, each group including a plurality of magnets having the same or different sizes and

arranged to provide a magnetic polarity and a magnetic flux density distribution. The plurality of field sub-assemblies are positioned with respect to one another to form a gap between the at least one of the plurality of field assemblies which includes the plurality of magnets, and another of the plurality of field assemblies. The coil assembly of this embodiment includes at least one coil positioned in the same plane within the gap, wherein the plane is substantially parallel to the direction of motion of the linear coil actuator.

It is to be understood that the present invention is not limited to a single coil, and that multiple coils can be employed. It is also to be understood that number of magnets comprising the group of magnets which supply a particular magnetic polarity is not limited in number to two magnets, but can be more than two. It is also to be understood that in accordance with the present invention, the sizes of the various magnets are varied according to the particular force characteristics sought to be achieved. This can include varying the length, width and/or thickness of the magnets, or any other variation of characteristics of the magnets which provides the desired magnetic flux density distribution in the air gap over the stroke length. Coil size is determined by the required force. The spacing set between smaller versus larger sized magnets (e.g. between 22B and 32B) within a polarity group is determined by the required flux density distribution. The spacing between one size of magnet in one polarity group (e.g. 22B) relative to the same size magnet (e.g. 34B) in another polarity group is determined by the stroke.

The terms and expressions employed herein are terms of description and not of limitation, and there is no intent in the use of such terms and expressions of excluding equivalents of the features shown and described, or portions thereof, it being recognized that various modifications are possible within the scope of the invention claimed.